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Operational and Environmental Impacts of Closed Cycle Cooling Systems

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Operational and Environmental Impacts of Closed Cycle Cooling Systems

by

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16. ABSTRACT The paper gives results of a study of operational and environmental impacts of closed cycle cooling systems, used for about a quarter of the nation's steam-electric generating capacity. Conclusions relating to operational impacts include: (1) closed cycle cooling leads to increased power plant heat rates relative to an open cycle cooling system, but is finding increased application at power plants in order to meet environmental or siting constraints (the wet cooling tower is the most often selected closed cycle cooling system); and (2) closed ycle cooling systems are more costly, in terms of both capital and annualized costs, than open cycle cooling (wet cooling towers are usually the least costly closed cycle cooling system, while dry cooling towers are the most expensive). Conclusions relating to environmental impacts include: (1) closed cycle cooling systems require less water from natural streams, and therefore have lower adverse intake effects than do once-through cooling systems for equivalent plants; (2) adverse impacts of closed cycle cooling can best be addressed through proper design; and (3) cooling tower blowdown can be controlled according to quality and volume by treatment and operation at the desired cycles of concentration (reuse of blowdown can greatly reduce or eliminate this plant discharge).

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Cooling Systems	Atmospherics	Stationary Sources	13A	20N
Steam Electric	Land Use	Terrestrial Effects		
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Operational and Environmental Impacts of Closed Cycle Cooling Systems

INTRODUCTION

Now serving about a quarter of the Nation's steam-electric generating capacity, closed cycle cooling systems* are increasingly being specified in this industry. This trend (see Table 1)[1] is the result of several factors, including consideration of technology-based effluent limitations in the issuance of water discharge permits and plant sitings in areas near fuel sources but with limited stream flows. Effluent guidelines following the enactment of the 1972 amendments to the Federal Water Pollution Control Act, which established zero-discharge by 1985 as the national goal, found that this goal could only be reached by closed cycle cooling systems[2]. In most cases, this meant evaporative, or wet, cooling towers. Despite the recent relaxation of thermal pollution guidelines, closed cycle cooling systems are still expected to find wide future application because of their advantages over once-through cooling systems relative to reduced environmental impacts on aquatic organisms and adaptability to using seasonally stored water.

Unfortunately, wet cooling towers also have disadvantages. In addition to being more costly than once-through cooling, they may discharge toxic chemicals in their blowdown to the environment, may produce problems associated with higher dissolved solids concentration resulting from evaporative water losses, may cause unwanted mist or fog, and may emit undesirable aerosol drift, especially when seawater or brackish water is the cooling medium. Although makeup requirements are but a few percent of those needed for open cycle systems, evaporative losses in water-scarce areas can be large enough to require the use of more expensive dry or combined wet/dry systems which also lead to lower plant thermal efficiencies.

THERMODYNAMIC CONSIDERATIONS

Insight into why using closed cycle cooling systems reduces the thermal efficiency of power plants, or alternatively leads to higher heat rates, can be gained by considering the Rankine cycle (Figure 1). Heat rejection, such as with a wet cooling tower, is shown by process C-D, and depends on ambient air conditions (wet bulb temperature and relative humidity). The steam saturation presure in the condenser during this process depends on the cooling water temperature, flow rate, and other properties of the

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*Closed cycle cooling systems as used here mean that the makeup waters required and blowdowns, if any, are small compared with the water circulated in the equivalent thermally rated once-through (open cycle) cooling systems.

cooling medium. In once-through cooling with water from a river or lake, process C'-D' is below that of process C-D in Figure 1. Thus, less heat would be rejected during process C'-D' than for process C-D which is for an evaporative cooling tower. Assuming all other conditions for the cycle were equal, the once-through cooling system would permit a higher thermal efficiency (lower heat rate) than the wet cooling tower as the turbine back pressure would be lower and allow a net increase of cycle work (turbine work minus pump work). Similarly, use of a dry cooling tower would shift process C-D upward to process C"-D" and lead to a lower thermal efficiency (higher heat rate) relative to a wet cooling tower. For example, cold water temperatures for condensing turbine exhaust steam at a given location might be 15.5°C (60°F, 0.25 psia), 32.2°C (90°F, 0.70 psia), and 54.4°C (130°F, 2.22 psia), respectively, for once-through, evaporative cooling tower, and dry cooling tower systems. Combined cooling systems (i.e., once-through cooling with a helping wet cooling tower or a combination of wet and dry cooling towers) could provide heat rates intermediate to those of their individual cooling modes, assuming all other conditions were the same.

The above discussion indicates that the cooling system used with a steam-electric power plant determines the lowest temperature in the plant's thermodynamic cycle. Ideally, this temperature is the temperature at which the turbine exhaust steam condenses. Although actual power plant cycles are more complex than the simple Rankine cycle, their efficiencies or heat rates are strong functions of the temperatures during the heat addition and heat rejection processes. Thus, the effect of turbine back pressure (or steam condenser pressure) is qualitatively similar for the ideal (Rankine) and actual thermodynamic cycles.

Frequently, the effect of steam condensing temperature on steam turbine exhaust pressure and plant efficiency is shown by turbine heat rate correction curves or heat rate tables. These heat rate corrections and corresponding outputs differ for different power plant cycles and specific power plants as well as load conditions. These corrections (see Figure 2 for a 1000 MW fossil-fuel plant)[3] show the change in heat rate relative to a fixed reference heat rate, the base heat rate at a given turbine exhaust pressure. For a fixed heat input to the power cycle, the product of power output and its corresponding heat rate at any exhaust pressure within the turbine's operational range equals the product of the base output and the base heat rate. Consequently, this relationship allows determination of the plant power output at off-design conditions.

ENERGY AND COST CONSIDERATIONS

Since closed cycle cooling systems would generally have higher heat rates than once-through cooling systems for the same steam electric generating unit, more fuel would be needed to meet a fixed electrical capacity with closed cycle cooling. If coal is the fuel, the additional

fuel consumption would have associated air pollutants (e.g., fly ash, SO_2, NO_x), solid wastes (e.g., bottom ash, fixed FGD wastes), and various wastewaters (e.g., cooling tower blowdown, water treatment wastes, boiler blowdown). While costs for the added fuel and equipment (including their procurement and uses) and disposition of associated wastes are readily assignable, the costs of environmental factors (health effects, future cleanup costs, etc.) are much more difficult, if not impossible to quantify. Consideration of other factors, such as employment resulting from obtaining, processing, and transporting fuel and other materials (e.g., SO_2 absorbent, FGD sludge, and water blowdown treatment) and producing, installing, operating, and maintaining pollution control equipment, would also seem to be appropriate in estimating the overall environmental costs and benefits.

Table 2 shows the costs of conventional cooling systems[4]. Since costs vary with locality and time, the costs shown are believed to be most appropriate for the relative ranking of the cooling systems listed. As expected, the once-through cooling system has the lowest total evaluated (sum of capital and penalty costs) cost, and dry cooling the highest. While the wet cooling tower has lower costs than the cooling pond in this table, this ranking could be reversed in site-specific cases, depending primarily on land requirements and costs for the cooling pond.

ENVIRONMENTAL CONSIDERATIONS

The operation of coal-fired power plants is accompanied by various emissions and discharges, some of which are shown in Figure 3. The environmental impacts of these emissions and discharges may be classified as (1) hydrological and aquatic, (2) atmospheric and terrestrial, and (3) land use, aesthetics, and noise[4]. Brief discussions of these impacts are noted below, while means of integrating controls to reduce undesired effects are discussed later.

Hydrological and Aquatic Impacts

These impacts stem from (1) intake structures for makeup water, (2) water consumption, and (3) cooling tower blowdown. While once-through cooling systems require water flows of about 0.05 m^3/s-MW (1 MGD/MW), wet cooling towers need several percent of their circulating water flows for makeup. This makeup, however, may not be small as illustrated by the 44 m^3/s (14.4 MGD) (enough for a city of 100,000) projected for one 1000 MW plant[4]. However, plants with dry cooling towers need only water to replace leakage.

If the makeup source is a water body or stream, the withdrawn water carries with it entrained organisms. Those organisms which are unable to avoid or escape entrainment can be impinged or destroyed by being

impinged on screens, exposed to water treatment chemicals, and mechanically and thermally stressed in components of the cooling systems. Nearly all the entrained plankton, which are mostly microscopic but also include larval forms of fish and shellfish, will be damaged or killed. Fish and shellfish impinged on the intake screens may be victims of starvation, exhaustion, oxygen depletion, or high pressure screen wash sprays. In addition to damaging or destroying these aquatic organisms, the performance of the cooling system may be reduced by flow obstructions which increase pressure losses or reduce flows.

The three general types of intakes (see Figure 4)--approach channel, offshore pipe, and bankside or shoreline--have a potential for high fish impingement and entrainment[5]. The approach channel (having conventional traveling screens) may trap fish, while some offshore intake pipes with high inlet velocities have entrained large numbers of fish. Modified designs of general intakes have reduced fish impingement significantly, but none appear to protect larval fish except when the intakes are placed away from areas of high larval fish density. Fine mesh screens (0.5 to 3 mm) in conjunction with low intake velocities in the screens (<0.15 m/s [0.5 ft/sec]) and wedge wire screens have shown some success in protecting early life stages (eggs, larvae, and young fish).

Since damage to aquatic organisms at a given site is proportional to the water volume withdrawn, and intakes for open and closed cycle cooling systems have similar environmental effects but of different scale, minimization of the withdrawal volumes would permit the greatest control for the intake effects problem. Thus, the coupling of blowdown reuse with the lower water withdrawal volumes for cooling towers, relative to once-through cooling, would reduce adverse intake effects.

Most water consumed by a wet cooling tower results from evaporation. This loss, although only 1-3 percent of the recirculating flow[4], may place a renewal burden on the water supply if the body from which the water is taken lacks the capability to replenish the supply in quality and quantity.

Consumption of water from cooling ponds includes both forced and natural evaporation. The former results from condenser cooling, while the latter represents water losses in the absence of heat rejection from the power plant. If the pond is built solely to serve the power plant, both the forced and natural evaporation are charged to the plant even though at some future time other beneficial uses of the pond may be reaped.

Consumptive water use by various categories, according to the 1978 study by the Water Resources Council, is given in Table 3[6]. Although the steam-electric category is the lowest consumer shown, it is the largest industrial water user, and closed cycle (evaporative) cooling is the highest consumptive water cooling system type. In the face of limited

water availability, wet/dry cooling may be required at water-scarce sites. Figures 5-7 show a typical wet/dry cooling tower, makeup required relative to annual water consumption, and plant performance as a function of water consumption and ambient temperature[3].

Cooling tower blowdown normally is the largest water discharge stream at plants with closed cycle cooling[7]. Using the mass balance relation in Figure 8, makeup and blowdown relative to evaporation are shown as a function of the cycles of concentration in Figure 9. Here, the cycles of concentration is the ratio of the total dissolved solids (TDS) concentration in the circulating water to the TDS concentration in the makeup. While increasing cycles of concentration reduces the makeup and blowdown requirements, the blowdown will have a higher concentration of salts (and possibly chemicals) and may require treatment prior to disposal, recycle, or reuse. In addition to having a high concentration of dissolved solids, blowdown may contain high chemical concentrations associated with the control of scaling, fouling, and corrosion. Since wet cooling towers scrub the air passing through them of various impurities (dust, pollen, SO_2, etc.), blowdown will contain these impurities or their reacted forms. Thus, depending on the amount and characteristics of the blowdown relative to the receiving body, some treatment prior to its discharge may be required to preclude ecological damage or to allow recycle/reuse of blowdown.

Atmospheric and Terrestrial Effects

These effects result from the discharge of large quantities of warm humid air into the atmosphere and subsequent settling and uptake of entrained impurities by biota. Although airborne heat and vapor emitted from closed cycle cooling systems are not classified as pollutants, the large amounts of water vapor released to the atmosphere on cooling may lead to weather modification through forming local fog or ice in the winter and increased precipitation. If the emitted water vapor mixes with stack flue gas or a nearby industrial stack plume containing reactive substances such as SO_2 and NO_x, environmental damage can occur from acid rainout.

Based on field observations[8], fogging and icing from natural draft cooling towers are not believed to cause environmental problems. At most, only a few millimeters of ice have been observed under a variety of meteorological conditions.

Fogging and icing have been observed for mechanical draft cooling towers[8]. Downwash effects associated with low tower heights have led to the buoyant plumes' intersecting the ground. When occurring, the plumes usually intersected the ground within a few hundred meters, with the plumes from towers having cells in a line more apt to impact the ground than plumes from cells aligned in circles. Plume and ground intersections have been observed from rectangular mechanical draft

towers about 10 percent of the time. Severe icing, which covered local structures and vegetation with about 6 mm (0.234 in.) of ice to a distance of nearly 250 m (76 ft), has also been observed.

Modification of weather, such as precipitation and cloud enhancement by wet cooling towers, has been minimal in the few documented cases[8]. Nearly all studies show precipitation and cloud enhancement for any single sector downwind from a tower are increased by only a few percent.

Drift, which may be guaranteed to not exceed 0.002 percent, is the fraction of circulating water through a cooling tower which is carried into the atmosphere as droplets. On leaving the tower, the droplets rise with the air/water vapor mixture but later may settle to the ground at various distances from the cooling tower depending on meteorological conditions. As the droplets evaporate, all constituents of the cooling tower water (suspended solids and dissolved solids, including water treatment chemicals) concentrate and, if deposited, can cause damage to nearby soils and vegetation as well as to materials and equipment susceptible to corrosion. If evaporation is complete, the resulting particulate adds to particulate air pollution and may be of inhalable particle size (<15 μm).

Drift depositions have considerable potential for biological impact through increased salt loading on vegetation, soil, and fauna. They can also alter the biotic components of an ecosystem. Drift effects may be compounded when cooling towers use brackish or ocean water (3,000 to 35,000 ppm dissolved salts), as deposition of salt on adjacent forests or agricultural land may damage or destroy real or potential commercial value.

Environmental factors influencing drift rate include wind speed and direction, ambient temperature, and relative humidity. Low relative humidity supports more rapid evaporation of droplets and leads to smaller salt particles with lower fall velocities. Thus, the particles remain airborne longer and impact the ground at a greater distance from the cooling tower.

Insufficient and inconclusive data exist on the degree of salt injury to biota from cooling tower drift[7]. Field data from the Chalk Point (brackish water) and Turkey Point (salt water) towers showed that acute drift effects may occur near the cooling tower, perhaps up to several hundred meters downwind; chronic effects from long-term operation of cooling towers are unknown but would be cumulative or impact other areas depending on the mobility of the deposited solids.

Cooling tower drift and its deposition from natural draft towers apparently do not increase ambient salt loading to the extent indicating significant impact. While field data from the Chalk Point and B. L. England Stations indicate that drift and its deposition from saltwater cooling towers may be significant near the towers, its impact beyond 1 km (0.63 mi) may be inseparable from the natural salt loading in those regions[7].

Methods for controlling drift are primarily engineering controls, physical controls, and type of tower design[4]. The proven engineering control has been the drift eliminator, which causes air flow to change direction rapidly. When this change occurs, water droplets from air impinge on the mist eliminator and collect to form larger droplets which have sufficient fall velocities to preclude their re-entrainment by the rising plume. Location of the tower to reduce drift and, if this is not possible, the use of a tower which maximizes dispersion are physical controls being practiced. Round mechanical draft towers and fan-assisted natural draft towers have drift dispersion capability intermediate to that of natural and mechanical draft towers.

The interaction of a cooling tower plume with stack gas can lead to the formation of toxic substances (sulfuric acid, sulfates, nitric acid, nitrates, etc.). Acid drops with a pH between 2 and 3 have been observed in the visible plume, but not at ground level, from a natural draft cooling tower[8].

Stack gas composition varies from plant to plant because of the fuel fired and environmental controls for these gaseous discharges. The oxidation rate of SO_2, a prerequisite of acid formation, in an interactive plume can be up to 6 percent/hr[7]. Heavy metals in fossil fuels, such as Pb, Mo, and Fe, can act as catalysts in promoting high sulfate reaction rates and add to the contaminant load of drift.

Since natural factors (such as humidity, temperature, wind speed and direction, and rate of precipitation) are not controllable, design parameters which contribute to plume interaction require control to minimize adverse environmental impacts. These include separation distance between the stack and cooling tower, SO_2 and NO_x control measures, and means to promote separation of the stack and cooling tower plumes, such as taller stacks and shorter cooling towers.

Land Use, Aesthetics, and Noise Impacts[4]

These impacts relate to quantity and use of land required by closed cycle cooling systems, their visual appearance, and noise emanating mostly from cooling tower fans and falling water. The siting of a closed cycle cooling system removes land from other constructive purposes. The siting may be accompanied by erosion, sedimentation, ground water contamination, defoliation, and habitat modifications which are particularly important considerations for cooling ponds having large land needs. Visual impacts and aesthetics are environmental factors requiring consideration, especially for natural draft cooling towers (because of their height) and mechanical draft cooling towers (because of their visible vapor plumes). Noise above background level is a major consideration where affected populations are significant or regulations must be met.

Of the available closed cycle cooling systems, cooling ponds require the most land, and mechanical draft cooling towers the least. However, the rationale for selecting one closed cycle cooling system over another involves many factors, including land and water availability, local climatology, socioeconomic factors, and local, state, and federal laws and regulations.

The impacts that these cooling systems may have on land are mainly those of construction which disrupts and often permanently alters the immediate habitat. The land that those cooling systems occupy is also lost to biota formerly occupying this land and may range from 0.4 to 1.2 hectares/MW (1 to 3 acres/MW) for cooling ponds to 0.012 hectare/MW (0.03 acre/MW) for mechanical draft wet cooling towers.

The visual impacts of cooling ponds, which closely resemble familiar natural bodies of water, are generally the least, while those of natural draft cooling towers, which may be 122 or 152 m (400 or 500 ft) high, are the most objectionable as they may be the dominant features in the immediate landscape. Consequently, the aesthetic impact analysis needs to consider site specific factors, such as opinions of people living near or at the viewpoints of the cooling system and the economic impact on real estate values in the visually impacted neighborhoods and on future neighborhood development.

The Noise Control Act of 1972 sets as its goal the attainment of an environment for all Americans free from noise which jeopardizes their health and welfare. EPA recommends a permissible average 24-hr noise level of 55 dBA L_{DN}* or an equivalent of 49 dBA[4].

Cooling towers can be a major source of power plant noise. This noise can be the result of (1) falling water in the tower, (2) movement of air through the tower, and (3) fan operation and bearing noises. Cooling tower noise measurements indicate that the sound level is almost independent of circulating flows (ranging from 615 to 1010 m^3/s [1.4×10^5 to 2.3×10^6 gpm]), and the average noise level at the top of a forced draft cooling tower is near 85 dBA. This level is not an on-site problem; however, the tower location is a critical problem at some sites if an equivalent of 49 dBA is to be met. For example, the noise from a natural draft cooling tower has been estimated to be 61 dBA at a distance of 152 m (500 ft) and does not fall to 50 dBA until the distance reaches 1067 m (3500 ft) from the tower[4].

Measures to control noise generated by falling water in cooling towers include splash decks or plates just above the water surface to create a gliding effect for water prior to entering the basin. This spacing between the cooling tower fill must be adjusted to reduce the high noise level due to narrow spacings. The reduction of this effect and that of falling water require tradeoffs which need further study.

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*L_{DN} is the sound energy averaged over a 24-hour period with a 10 dB night-time weighting.

Noise emanating from fans, motors, and their bearings can be kept low by proper maintenance and lubrication. Two-speed motors for fans permit reduced noise by operation at the lower speed at night and higher speed in daytime. Air flow silencers and barriers are other noise reduction techniques when tower siting precludes the needed control of noise. In general, forced draft cooling towers have higher noise levels than natural draft towers. However, in selecting a cooling tower system, other factors such as visible plume and aesthetics may outweigh noise level as selection criteria.

INTEGRATED POLLUTANT CONTROL OPPORTUNITIES

Proper site and equipment selection and use of good engineering design practices are important in avoiding some of the adverse environmental impacts noted above. Minimization of adverse intake effects, cooling tower drift and noise, and stack gas plume/cooling tower plume interactions are best addressed through proper design. However, other environmental impacts can not be avoided, but can be mitigated. Remedies include water reuse/recycle, waste heat utilization, and combined waste disposal.

Water Reuse/Recycle

Blowdown from a wet cooling tower, normally the major wastewater stream at power plants with a closed cycle cooling system, can serve as makeup to the flue gas desulfurization (FGD) system or for other lower quality water needs such as ash sluicing. Wet FGD systems may use up to 10 percent of the plant makeup water and could receive adequate water from blowdown of cooling towers operating at 10 to 12 cycles of concentration, provided that chemicals in and the composition of the blowdown are compatible with acceptable FGD system performance[7]. Since many U.S. plants operate at cycles of concentration between 2 and 10, the quantity of blowdown would be adequate for FGD makeup. Recalling Figure 9, the ratio of makeup to evaporation is 1.11 and that of blowdown to evaporation is 0.11 at 10 cycles, assuming negligible drift. These ratios become 1.09 and 0.09, respectively, at 12 cycles of concentration.

Low quality water from various power plant uses may be upgraded through selected treatment prior to reuse. For example, a sidestream precipitation process may be used to reduce sulfate and silica levels in circulating water, while blowdown can be upgraded for reuse via reverse osmosis or evaporation processes, such as flash evaporation or vacuum compression distillation.

Pilot studies with lime spray dryers have indicated that cooling tower blowdown or its equivalent is suited for slurry dilution or trim water for temperature control in the spray dryer[4]. Blowdown, however, was not recommended for lime slaking[9].

Waste Heat Utilization

As noted earlier, condensation of turbine exhaust steam necessitates heat rejection to cooling water, and this energy is often called waste heat, although it is a consequence of the second law of thermodynamics and not a willful waste of energy. This low quality energy from the perspective of thermodynamics may be used beneficially in selected cases.

One such case at a power plant involves concentrating wastewater through evaporating a portion of the wastewater while obtaining the required heat from cooling water diverted from cooling tower inflow. As practiced at the C.D. McIntosh Unit 3 in Lakeland, Florida, the unique binary cooling tower (BCT) has Mylar plastic film membranes as heat exchange modules, and air over the heat exchange surfaces evaporates the wastewater using energy for evaporation from warm cooling tower circulating water[10]. About 10 percent of the cooling water flows through the BCT and provides 9.09 kJ/s (130×10^6 Btu/hr) at the design load to evaporate 0.843 m^3/s (192 gpm) of the 0.879 m^3/s (200 gpm) of wastewater entering the BCT. This cooling rate augments the cooling system capacity by 7 percent, and increases power plant output through lowering turbine backpressure.

Another approach being evaluated at Southern California Edison's (SCE's) Etiwanda Station is shown in Figure 10[11]. This process uses turbine exhaust steam (40-50°C [104-122°F]) to concentrate cooling tower blowdown through evaporation of a portion of the blowdown. It can also use seawater as feed. The vapor is condensed ($\leq$5 ppm salt) and used as a high quality makeup, while the residual blowdown at 17 to 20 cycles of concentration is further concentrated to 50 cycles before disposal. This process uses a vertical tube evaporator with double-fluted aluminum-brass tubes and a small amount of a proprietary detergent to enable a foamy flow to enhance heat transfer. The 190 m^3/day (50,000 gpd) unit was built at the Sea Water Conversion Laboratory of the University of California under an EPA grant. Earlier testing at the Etiwanda Station involved the joint sponsorship of EPA, EPRI, SCE, and Envirotech Corporation. The present test program has the sponsorship of EPA, SCE, and Water Services of America, Inc. It is designed to obtain long-term performance data to complement earlier test data and serve commercialization purposes.

Greenhouse heating is another commercial application of waste heat from power plant cooling water. At least two such ventures are now operating: one at Northern States Power's Sherco Plant has been underway for about 6 years and encompasses 1.6 hectares (4 acres)[12], while the 1.1-hectare (2.75-acre) greenhouse at Pennsylvania Power and Light's Montour Station has been operational since late 1980[13]. Both operations focus mainly on high cash crops such as roses and other flowers, but 0.5 acre of the Sherco complex is devoted to hydroponic farming. Figure 11 depicts the arrangement of the Sherco greenhouses relative to the power plant.

Although these greenhouses use power plant waste heat for commercial purposes, the fraction of heat used beneficially is quite small relative to the total heat rejected at the respective plants and is seasonal. Both utilities have additional acreage set aside for commercial waste heat utilization, but in both cases this acreage would increase beneficial use of waste heat to only a small percentage of rejected heat available if such use were for greenhouse heating.

Other opportunities for beneficial utilization of low grade energy include integrated energy conversion/use complexes which use energy more efficiently[14]. The energy conversion facilities, such as steam-electric generating plants, could provide district heating in conjunction with off-peak storage and on-peak use for electrical power and heating application, industrial process heating, and a combination of these options.

Waste disposal costs may be reduced and handling simplified through combining streams prior to treatment or disposal. For example FGD sludge, fly ash, bottom ash, and cooling tower blowdown could be combined and then disposed of. However, care must be used not to preclude lowest cost disposal by contamination of nonhazardous wastes with hazardous ones. Too, local requirements on waste disposal may limit the combination of various power plant wastewater streams or combining certain liquid and solid wastes.

CONCLUSIONS

From the preceding discussion, the following conclusions may be drawn:

Operational Impacts

1. Closed cycle cooling leads to increased power plant heat rates relative to an open cycle cooling system, but is finding increased application at power plants in order to meet environmental or siting constraints. The wet cooling tower is the most often selected closed cycle cooling system.

2. Closed cycle cooling systems are more costly, in terms of both capital and annualized costs, than open cycle cooling. Wet cooling towers are usually the least costly closed cycle cooling system, while dry cooling towers are the most expensive.

Environmental Impacts

1. Closed cycle cooling systems require less water from natural streams (rivers, lakes, etc.), and therefore have lower adverse intake effects than do once-through cooling systems for the equivalent plants. In addition, heat rejection is primarily to the atmosphere and not to a water body so that significant thermal pollution is avoided. However, water consumption is greater for evaporative cooling towers than for once-through cooling systems.

2. Adverse impacts of closed cycle cooling, such as cooling tower drift, large land use, cooling tower noise, and stack gas plume/cooling tower plume interactions, can be best addressed through proper design.

3. Cooling tower blowdown can be controlled according to quality and volume by treatment and operation at the desired cycles of concentration. Reuse of blowdown can greatly reduce or eliminate this plant discharge.

Integrated Pollutant Control Opportunities

1. Cooling tower blowdown, the major waste stream at power plants using closed cycle cooling, can be reused or renovated for recycling. The FGD system is the main candidate for reuse, while treatment can upgrade blowdown for recycling or for higher water quality uses.

2. Limited opportunities for beneficially using heat rejected to cooling water are available, but several commercial applications include wastewater treatment and greenhouse heating.

3. Combining wastes, such as FGD sludge, fly ash and bottom ash, may simplify and reduce the costs of waste disposal. Care must be exerted to preclude combining hazardous with non-hazardous wastes to limit disposal costs.

REFERENCES

1. Steam-Electric Plant Air and Water Quality Control Data (Summary Report), DOE/FERC 0036, Federal Energy Regulatory Commission, Washington, DC, October 1979.

2. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Steam Electric Power Generating Point Source Category, EPA 440/1-74-029a (NTIS PB 240853), U.S. EPA, Washington, DC, October 1974.

3. Hu, M.C. and G.A. Englesson, Wet/Dry Cooling Systems for Fossil-Fueled Power Plants: Water Conservation and Plume Abatement, EPA-600/7-77-137 (NTIS PB 276625), U.S. EPA, Industrial Environmental Research Laboratory, Research Triangle Park, NC, November 1977.

4. Senges, D.C., et al., Closed-Cycle Cooling Systems for Steam-Electric Power Plants: A State-of-the-Art Manual, EPA-600/7-79-001 (NTIS PB 299290), U.S. EPA, Industrial Environmental Research Laboratory, Research Triangle Park, NC, January 1979.

5. Brna, T.G., Approaches for Coping with Some Environmental Concerns of Cooling Systems, Paper presented at the 72nd Annual Meeting, American Institute of Chemical Engineers, San Francisco, CA, November 1979.

6. Hu, M.C., G.F. Pavlenco, and G.A. Englesson, Water Consumption and Costs for Various Steam Electric Power Plant Cooling Systems, EPA-600/7-78-157 (NTIS PB 285397), U.S. EPA, Industrial Environmental Research Laboratory, Research Triangle Park, NC, August 1978.

7. Wells, R.M., T.R. Blair, and M.L. Owen (Radian Corporation), Flue Gas Desulfurization in the Totally Integrated Power Plant. Paper presented at the Integrated Environmental Control for Coal-Fired Power Plants Symposium, Denver, CO, February 22-25, 1981.

8. Englesson, G.A. and M.C. Hu, Nonwater Quality Impacts of Closed-Cycle Cooling Systems and the Interaction of Stack Gas and Cooling Tower Plumes, EPA-600/7-79-090 (NTIS PB 80-102387), U.S. EPA, Industrial Environmental Research Laboratory, Research Triangle Park, NC, March 1979.

9. Parsons, E.L., Jr., L.F. Hemenway, O.T. Kragh, T.G. Brna, and R.L. Ostop, "SO_2 Removal by Dry FGD," in Proceedings: Symposium on Flue Gas Desulfurization-Houston, October 1980, Vol. 2, EPA-600/9-81-019b (NTIS PB 81-243164), April 1981, pp. 801-852.

10. Friedlander, G.D., "Zero-Discharge Stations Gain Favor," Electrical World, March 1982, pp. 103-108.

11. Sephton, H.H. and K. Someahsaraii, Waste-Heat Vertical Tube Foam Evaporation for Cooling Tower Blowdown Renovation/Recycle, Draft report prepared for the U.S. EPA, Industrial Environmental Research Laboratory, Research Triangle Park, NC, under Grant No. R803678, February 1982.

12. Boyd, L.L., et al., A Demonstration of Beneficial Uses of Warm Water from Condensers of Electric Generating Plants, EPA-600/7-80-099 (NTIS PB 80-196793), U.S. EPA, Industrial Environmental Research Laboratory, Research Triangle Park, NC, May 1980.

13. Johnson, R.P., et al., "Montour Waste Heat Greenhouse Project," in Proceedings: Third Conference on Waste-Heat Management and Utilization, EPA-600/9-82-008 (NTIS PB 82-227901), May 1982, pp. VII-A-525-537.

14. Brna, T.G. and C.C. Lee, "Environmental Approaches to Waste Heat Utilization," in Proceedings: Third Conference on Waste Heat Management and Utilization, EPA-600/9-82-008 (NTIS PB 82-227901), May 1982, pp. II-9-17.

TABLE 1. COOLING SYSTEMS AT STEAM-ELECTRIC POWER PLANTS[1]

Type of Cooling	Percent of Total Installed Capacity							
	1969	1970	1971	1972	1973	1974	1975	1976
Once-through, Fresh	50.5	50.1	47.7	45.4	43.1	41.1	39.4	38.9
Once-through, Saline	23.5	22.8	21.5	20.9	20.1	18.9	18.5	17.7
Cooling Ponds	5.9	6.7	7.3	8.0	8.6	8.5	9.0	8.9
Cooling Towers	10.9	11.2	12.9	13.4	14.4	16.1	16.6	17.5
Combined Systems	9.2	9.2	10.6	12.3	13.8	15.4	16.5	17.0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
No. Plant Reports	651	681	689	695	769	787	789	779
Total Capacity, 1000 MW	243	262	283	310	340	372	395	410

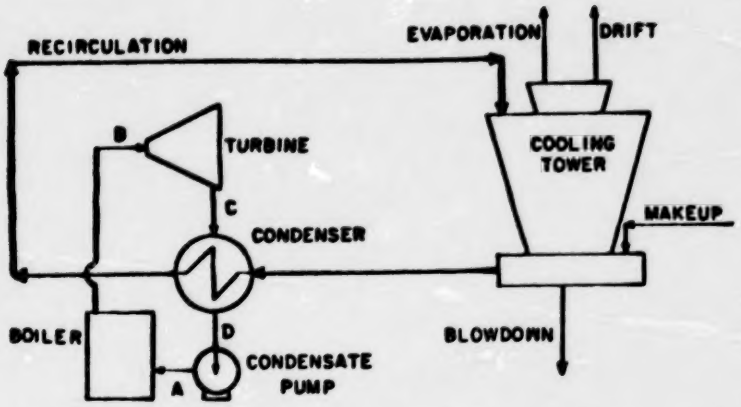
TABLE 2. COSTS OF TYPICAL CONVENTIONAL COOLING SYSTEMS FOR FOSSIL FUEL POWER PLANTS (1978 DOLLARS)[4]

Cooling System	Capital Cost, $/kW	Penalty Cost, $/kW	Total Evaluated Cost, $/kW	Total Evaluated Cost, mills/kWh
Once-through	15.16	6.36	21.52	0.60
Mechanical Draft Wet Cooling Tower	21.57	27.72	49.29	1.35
Natural Draft Wet Cooling Tower	29.96	21.02	47.98	1.31
Fan-assisted Natural Draft Wet Cooling Tower	27.77	22.73	50.50	1.38
Constructed Cooling Pond	38.50	32.74	71.24	1.95
Power Spray Module Canal	23.99	25.63	49.62	1.36
Mechanical Draft Dry Cooling Tower	34.29	125.04	159.33	4.37
Natural Draft Dry Cooling Tower	37.87	115.98	153.85	4.22

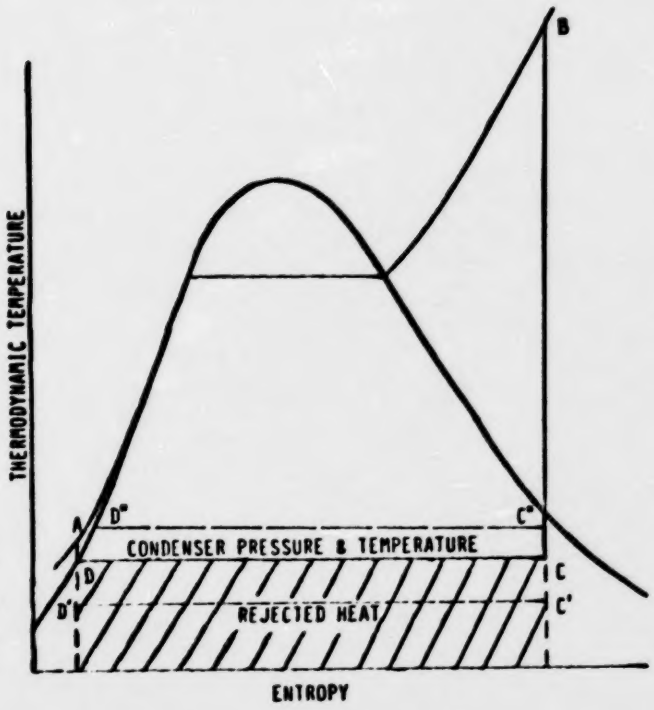
TABLE 3. PROJECTED CONSUMPTIVE WATER USE, MGD*[6]

Category	Year 1975	1985	2000
Public Supply	8,485	9,594	10,978
Agriculture	99,149	107,281	107,467
Industry & Mining	8,130	11,395	17,760
Steam-Electric	1,440	4,110	10,598
Total Consumption	117,204	132,380	146,803

*1 MGD = 0.0438 m^3/s



1a. Simple Power Plant Cycle Flow Diagram



1b. Simple Rankine Cycle

Figure 1. Flow and Temperature-Entropy Diagrams for a Rankine Power Cycle.

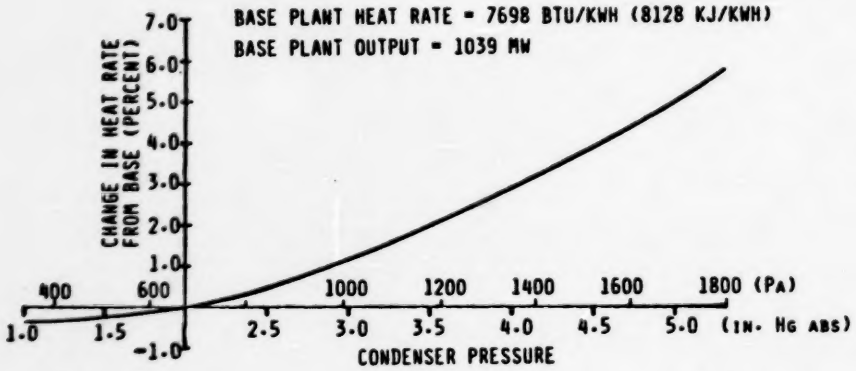


Figure 2. Typical Heat Rate Correction Curve for a Fossil-Fuel Power Plant With Conventional Turbine[3].

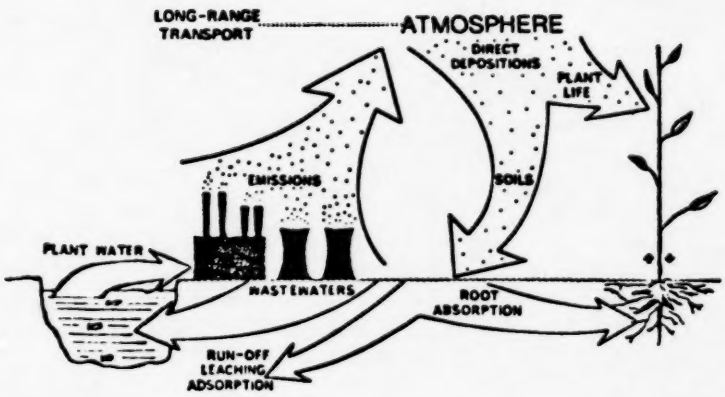
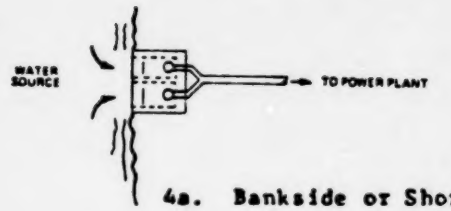
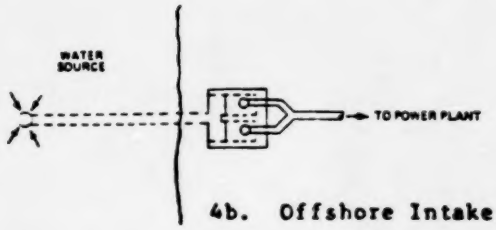


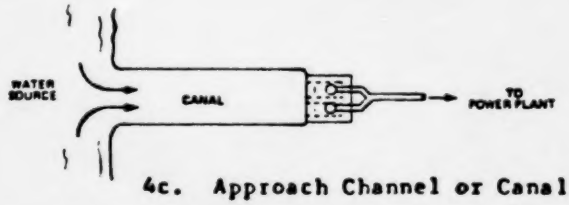
Figure 3. Possible Interactions Between Power Plant Emissions and Discharges and the Environment.



4a. Bankside or Shoreline Intake



4b. Offshore Intake



4c. Approach Channel or Canal Intake

Figure 4. Intakes for Steam-Electric Generating Stations[5].

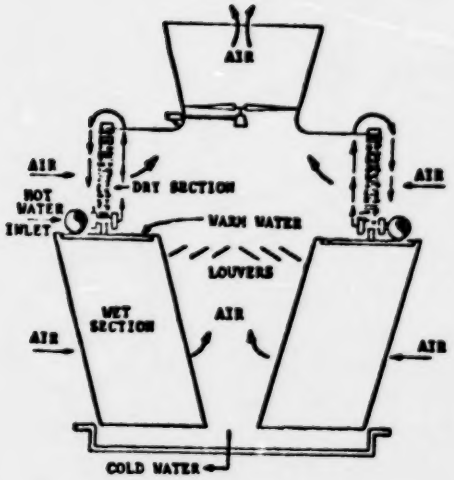


Figure 5. Wet/Dry Mechanical Draft Cooling Tower (Parallel Air Flow)[3].

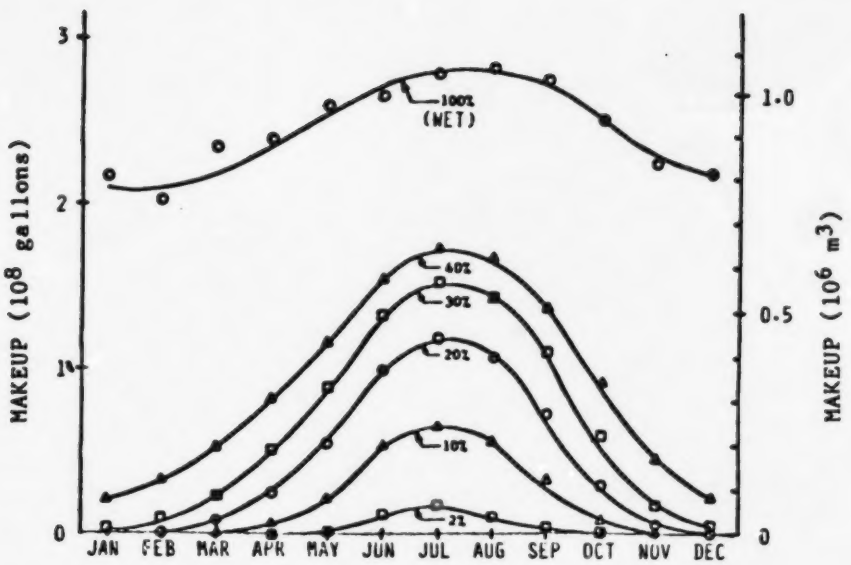


Figure 6. Total Monthly Makeup Requirements of Wet/Dry Cooling Systems for Water Conservation: 1000 MW Coal-Fired Power Plant at San Juan, New Mexico[3].

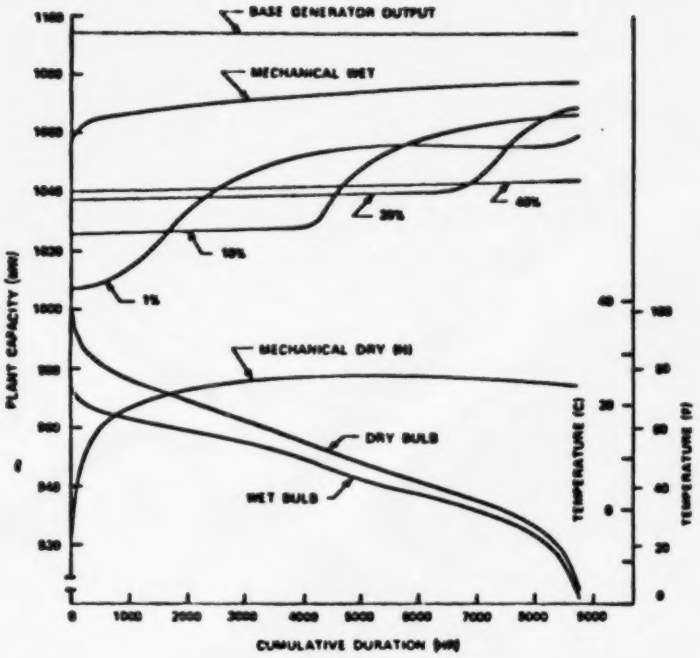


Figure 7. Plant Performance Characteristics (Net Output) Using Wet/Dry Cooling Systems[3].

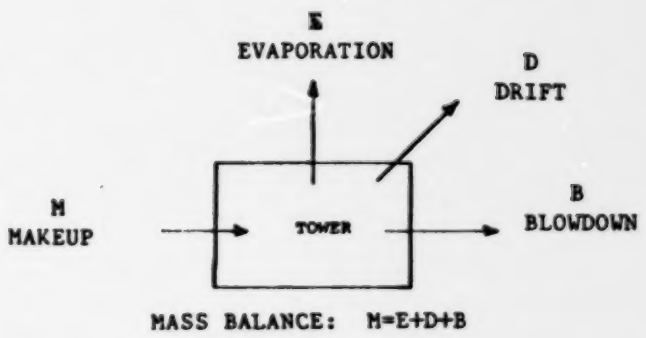


Figure 8. Flow Diagram for an Evaporative Cooling Tower.

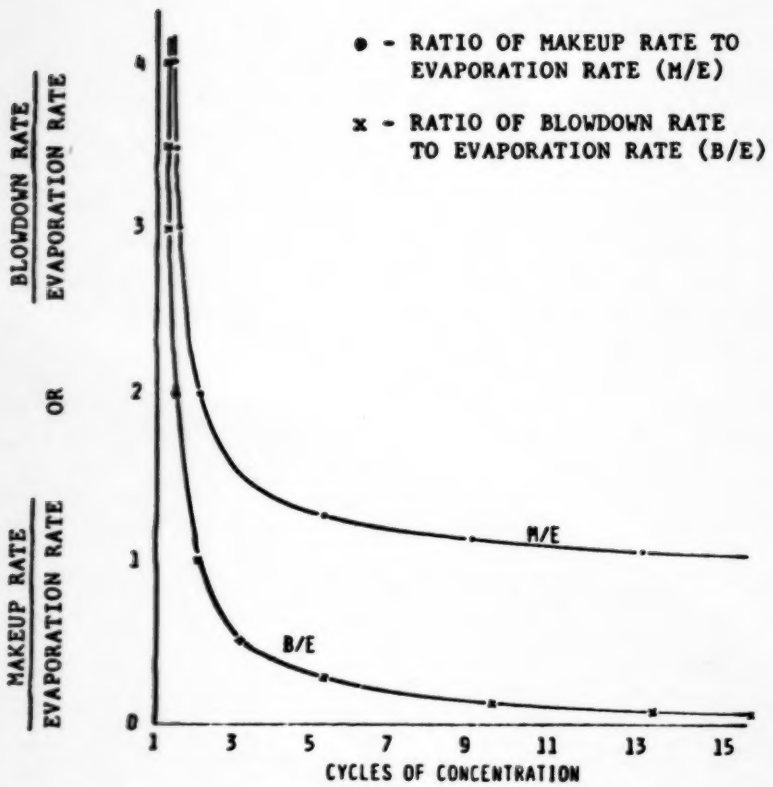


Figure 9. Makeup and Blowdown for an Evaporative Cooling Tower As A Function of Cycles of Concentration.

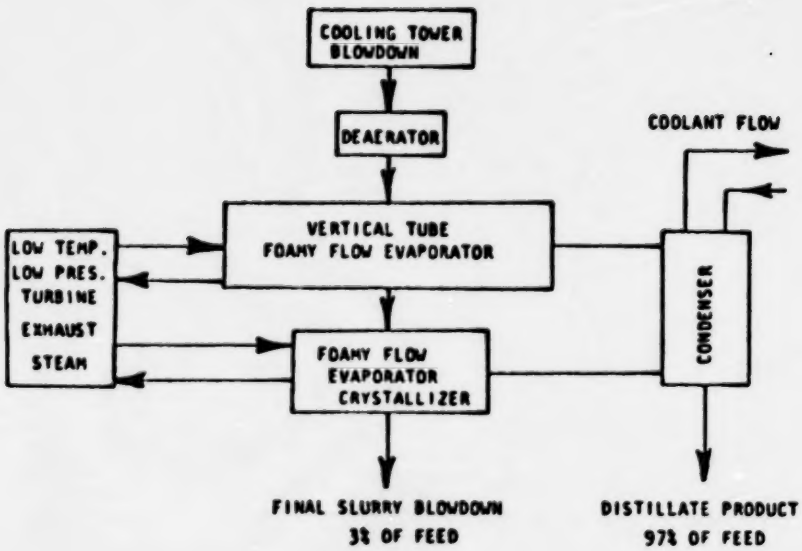


Figure 10. Simplified Diagram Showing the Waste Heat-Vertical Tube Foamy Flow Evaporator Process[11].

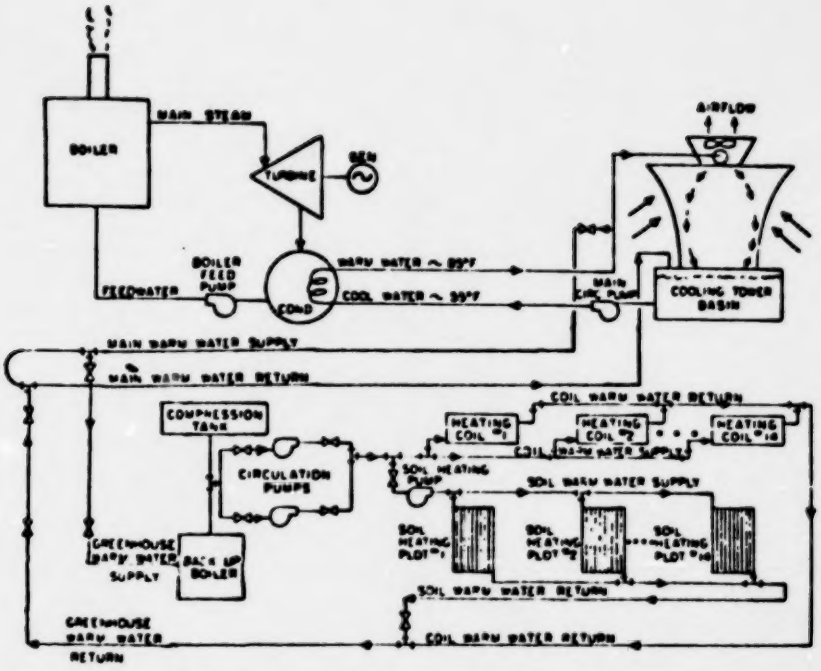


Figure 11. Sherco Greenhouse Water Flows Relative to Steam-Electric Plant[12].

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